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Office of Research,
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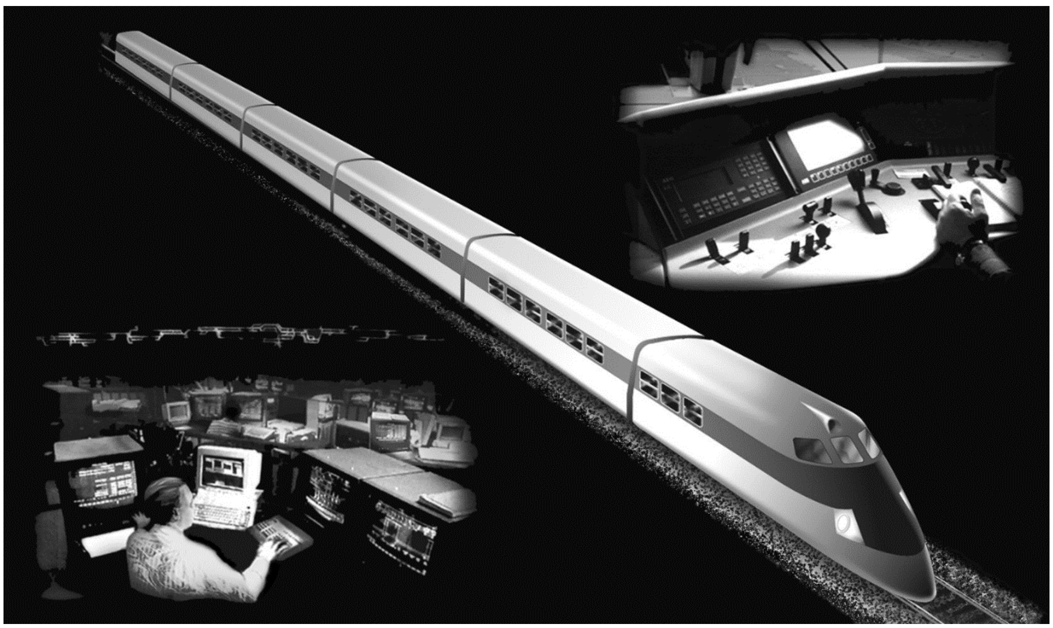
Washington, DC 20590

An Analysis of Freight Railroad Voice Communications



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13. ABSTRACT (Maximum 200 words)
This report documents the results of a study of railroad voice communications from three large (Class I) freight railroad dispatch centers. The purpose of the research was to gain an understanding of the types of information that are exchanged between railroad personnel and to determine the types of communication errors that occur between communicating parties. Voice communications from signal, dark, and mixed territories were analyzed with respect to the parties to communications, message content, and the errors that took place. Within the current study, 79 percent (n = 3930) of the transactions contained at least one error. Ninety-five percent of all errors went undetected. Of the 5 percent of errors that were caught and corrected, 55 percent were catching and correcting another's error. The remaining 45 percent corrected their own error. If radio communication continues to be part of the communication relay in the railroad system, enhanced training for all railroad employees in procedures in communication could be a great benefit. Training that is established and standardized throughout the railroad culture has the potential to lessen the errors that occur during radio communication.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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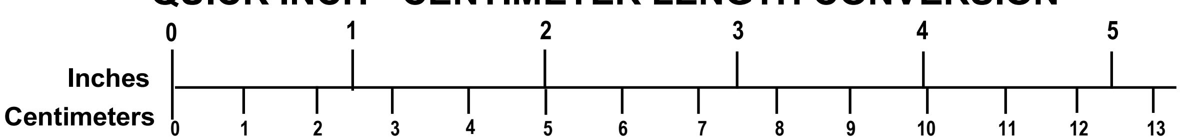

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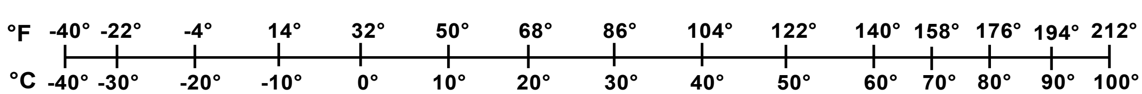

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Contents

Tables

Executive Summary

As the railroad industry moves from analog to digital communication, understanding current railroad communications will help to measure the impact of new forms of communication. Documenting the content of railroad communications and the errors that occur within them enable the railroads and FRA to identify the impact of new communication technology on communication performance and safety.

In this study, the Federal Railroad Administration sponsored a research team from Volpe National Transportation Systems Center (Volpe) to study railroad voice communications from three large (Class I) freight railroad dispatch centers. This report documents the content and resulting errors in railroad communications for mainline freight operations to create a baseline to evaluate the impact of new forms of communications between dispatchers, train crews, and maintenance-of-way employees.

Researchers identified 6,066 transactions in the data from the three railroads. The procedure included a transaction identification task that required that the coder parse out each transaction from the original dispatch recordings and create its own sound file. The team listened to each transaction and coded communication factors using the taxonomy shown in Appendix A. Researchers found communications content dominated by conversations between the dispatcher and train crew. The dispatcher initiated the most conversations followed by the conversations between dispatchers and roadway workers. Most conversations (87 percent) were initiated by the dispatcher.

Researchers found 79 percent of all transactions contained at least one error. Ninety-five percent of all errors went undetected. Of the 5 percent of errors that were caught and corrected, 55 percent involved correcting someone else's error. The remaining 45 percent corrected their own error.

The research team collected 860 hours of voice recordings from three Class I freight railroads with a final dataset totaling of 384 hours of radio transactions received. The recordings came from 16 non-consecutive 24-hour periods from March 2005 to June 2006. The recordings came from six territories or "desks." Each desk represents a geographic territory managed by a single dispatcher. There were three shifts in a 24-hour period, resulting in three dispatchers managing that territory over a 24-hour period. Although the overall number of transactions analyzed was small relative to the total number of desks or territories for the three railroads, the sample nevertheless represented the largest sample of U.S. railroad communications analyzed to date.

1. Introduction

The Federal Railroad Administration sponsored Volpe National Transportation Systems Center (Volpe) to study railroad voice communications from three large (Class I) freight railroad dispatch centers. The purpose of the research was to gain an understanding of the types of information that are exchanged between railroad personnel and to determine the types of communication errors that occur between communicating parties. Voice communications from signal, dark, and mixed territories were analyzed with respect to the parties to communications, message content, and the errors that took place. Within the current study, 79 percent (n = 3930) of the transactions contained at least one error. Ninety-five percent of all errors went undetected. Of the 5 percent of errors that were caught and corrected, 55 percent were catching and correcting another's error. The remaining 45 percent corrected their own error. If radio communication continues to be part of the communication relay in the railroad system, enhanced training for all railroad employees in procedures in communication could be a great benefit. Training that is established and standardized throughout the railroad culture has the potential to lessen the errors that occur during radio communication.

1.1 Background

As the industry moves from analog to digital communication, understanding current railroad communications will help to measure the impact of new forms of communication. Documenting the content of railroad communications and the errors that occur within them enable the railroads and FRA to identify the impact of new communication technology on communication performance and safety.

1.2 Objectives

This report documents the content and resulting errors in railroad communications for mainline freight operations to create a baseline to evaluate the impact of new forms of communications between dispatchers, train crews, and maintenance-of-way employees. The purpose of the research was to gain an understanding of the types of information that are exchanged between railroad personnel and to determine the types of communication errors that occur between communicating parties.

1.3 Overall Approach

Researchers collected 860 hours of voice recordings from three Class I freight railroads with a final dataset totaling of 384 hours of radio transactions received. The recordings came from 16 non-consecutive 24-hour periods from March 2005 to June 2006. The recordings came from six territories or "desks." Each desk represents a geographic territory managed by a single dispatcher. There were three shifts in a 24-hour period, resulting in three dispatchers managing that territory over a 24-hour period. Although the overall number of transactions analyzed was small relative to the total number of desks or territories for the three railroads, the sample nevertheless represented the largest sample of U.S. railroad communications analyzed to date.

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1.4 Scope

This research focused on railroad voice communications from three large (Class I) freight railroad dispatch centers. Voice communications from signal, dark, and mixed territories were analyzed with respect to the parties to communications, message content, and the errors that took place.

1.5 Organization of the Report

Section 2 discusses the current state of communications in the railroad industry. Section 3 discusses the methods used in the research. Section 4 presents a discussion of the results. Section 5 discusses conclusions reached from the research.

2. Communication in the Railroad Environment

Effective communication in railroad operations contributes to the safe and efficient movement of trains, maintenance activities, and the speedy transmission of emergency information. With more than 240,000 route miles in the U.S. and Canada, the vast network of trains and track needs to be monitored to function efficiently within the larger railroad community (Reh, 1996). Most railroad communications between train dispatchers and locomotive engineers, maintenance-of-way (MOW) crews, and signal maintainers occurs via voice radio transmissions, with a smaller percentage of communications over mobile telephone or other modes. Communication breakdowns can occur for a variety of reasons, including employees' cognitive limitations, equipment failures, and improper procedures. Existing communications research covers a variety of topics, such as technology and equipment, procedures, and errors in radio communication resulting in railroad accidents (Jones & Hickey, 2004; Murphy, 2001).

At this writing, the railroad industry is gradually replacing the analog, voice-based communication systems with digital systems. Information that speakers currently convey orally may now be made visually. While technology holds the promise of making communications more efficient and secure, it may also change communication processes in unintended ways. For example, information currently shared on a party line may be shared via channels that lack a party line. This change may create some unintended consequences since party lines have been beneficial in alerting other train crews of potential hazards or emergencies that may inadvertently impact them. Will this information be conveyed to other train crews in the future? By documenting who communicates with whom as well as what they communicate and the kinds of errors that can contribute to unsafe conditions, a baseline can be used to understand the impact of new communication technology. The focus of this report is to document the content of railroad communications for mainline freight operations.

2.1 Communicators

Communication between employees keeps the railroad system functioning smoothly. Table 1 below describes the different types of communicators in the railroad environment.

Dispatchers are central to the daily communication that takes place during train movements and maintenance work in mainline operations. The railroad dispatcher is responsible for the daily management of the track, including the safety of maintenance workers on and around the track itself. At the same time, the dispatcher must keep the trains moving efficiently. On Class I freight railroads, multiple dispatchers monitor train movements because of the high volume of trains and the physical extent of the tracks (Reh, 1996). Voice communication is one of several ways in which the dispatchers manage the movement of trains and equipment. Some of the communications involve answering requests from the different railroad employees, monitoring current railroad operations, and coordinating the operations with others who might be impacted in the environment. (See Roth, Malsch, and Multer [2001] for more details on the railroad dispatcher's responsibilities.)

Table 1. Examples of Railroad Employees

Communicator Group	Examples
Dispatcher: A dispatcher manages the allocation of track between the movement of trains and equipment and maintenance operations. The dispatcher will also coordinate the movement of trains in an assigned territory.	Assistant Chief Dispatcher Dispatcher
Roadway Crew: Employees and contractors who work on or near the track itself to construct, maintain, or inspect the track and wayside infrastructure.	Track Inspector Track Foreman Road Master Signalman Flagman
Yard Crew: Individuals who work in a complex series of railroad tracks for storing, sorting, or loading/unloading railroad cars and/or locomotives.	Yardmaster Yard Locomotive Engineers Switchmen
Train Crew: Individuals involved in the operational and safety duties that may involve actual operation of the train.	Road Foreman Locomotive Engineer Conductor Train Masters Brakeman
Emergency Personnel: Individuals who monitor the railroad system and are on call for emergency situations as they arise on the right-of-way (ROW).	Railroad Police Local Police Emergency Medical Staff Fire Department

2.2 Communication Failure

There are a variety of ways in which communication failure can occur. Factors such as equipment, procedures, or the communicators themselves can play a role (Jones and Hickey, 2004). One factor that makes communications challenging and contributes to communication failure is the temporal nature of oral communications. The receiver needs time to encode the information communicated by the speaker before it can be processed. The transient nature of spoken information imposes limits on the amount of information that an individual can encode or retain in short-term memory. Communicating more information than a human memory can code means the receiver may fail to remember or remember it incorrectly. To address these limitations on information retrieval, railroads adopted formal procedures and a restricted language to communicate safety-sensitive information. Since short-term memory is predominately acoustic coding, the need for verbal rehearsal of the information is critical for information retention. Both aviation and railroads adopted the readback-hearback procedure to mitigate the potential for communication failure resulting from the process by which short-term memory works (Matlin, 2005). This procedure requires the receiver to repeat or read back the message communicated by the sender. The sender listens to the message repeated back by the receiver to confirm that the message was correctly interpreted and correct any information that was miscommunicated.

Research on radio communication errors in aviation provides a framework for thinking about communication failures in the railroad environment. The types of communication errors in air traffic control (ATC) communications may also occur in the railroad environment (Burki-Cohen, 1995; Cardosi, Brett, and Hans, 1996). Communications errors include transposition errors, relaying incorrect information, omitting information, using an incorrect procedure, and frequency congestion or radio interference. One type of error found in both modes is the use of non-standard phraseology. For example, in the railroad environment a dispatcher issues a Form D for track occupancy, and the train crew is required to read back all instructions verbatim. Following the readback, the dispatcher is required to state the effective time of the instruction and the receiver is also required to read back the effective time. If a dispatcher fails to state the effective time of a Form D following the readback then a phraseology error has occurred (Doran & Multer, 2009). In the following sections, this study discusses three common types of communication errors.

2.2.1 Readback Errors

Communication in both the aviation (Title 14 Code of Federal Regulations [CFR] Part 91.123) and railroad (49 CFR Part 220) environments involve rules and regulations to standardize spoken language for safety-critical communications, to make them clear and concise and minimize the potential for errors. In both modes, the receiver is required to repeat back safety-critical instructions from the sender. Without this readback, the dispatchers (in the railroad environment) and the air traffic controller (in the aviation environment) would not know if the recipient received and understood what action they were required to take. In aviation, ATC and pilots have specific communication protocols to follow which include a complete readback of ATC instructions from the pilot to acknowledge proper receipt of the message. Any departure from the readback protocol is considered a procedural error. Deviations from the readback protocol occur in less than 1 percent of all communications. However, 50 percent of the deviations (pilot readback) were not corrected by the receiver of the readback (ATC), allowing the erroneous information to become part of the communication (Burki-Cohen, 1995; Cardosi, Brett, and Hann, 1996).

Gibson, Megaw, Young, and Lowe (2006), found that respondents failed to adequately repeat back complete communications in 83 percent of the 188 transactions between signalers (dispatchers) and trackside workers. However, in 50 percent of the 188 transactions, the time/date information was read back correctly, while the content of communication was not. This finding suggests that time/date information might be less prone to errors or omissions than other information transfers between communicators. Across domains, most readback errors occur when numbers are either omitted or read back incorrectly to the other party (Gibson et. al., 2006). In many cases, communicators detect and correct their errors. The recovery rate, or ability to correct one's own error, in readbacks in the ATC environment was 61 percent (Burki-Cohen, 1995; Cardosi et al., 1996). In the railroad environment, error recovery was 47 percent (Gibson et. al., 2006).

Each readback error can be classified as a phraseology error or a numerical error. The next section describes these types of errors and past research on its occurrence in both the aviation and railroad modes.

2.2.2 Phraseology and Numerical Errors

In railroad operations, phraseology errors occur when communicators fail to speak using the proper phraseology requested by the railroads. For example, if the crew spoke, "West on track 2, t-w-o," and failed to spell out "west," since each speaker has a different intonation and accent, a word might be more open to misinterpretation by the receiver. Instead, following the procedure may increase the likelihood that receivers will hear and understand the sender's message correctly. Phraseology errors can occur for several reasons, including lack of experience with the communication rules and/or procedures, distractions, extreme levels of workload (high or low), or divergence between what the receiver expected to hear and what the sender said. Corradini and Cacciari (2001) found that during ATC communications, non-standard phraseology occurred in 48 percent of all transactions. In the railroad environment, Jones and Hickey (2004) found that 94 percent of all transactions involving dispatchers or locomotive engineers failed to use standard phraseology, such as stating "out" at the end of a transaction or not using the phonetic alphabet. Doran and Multer (2009) found in their dataset that only 9 percent of the total errors were phraseology errors.

Another study (Gibson et. al., 2006) found locomotive engineers used numbers correctly in 74 percent of the transactions and dispatchers in 92 percent of the transactions. Thirty-five percent of all transactions contained the omission of the dispatcher's identity and location, the equivalent to an aviation call sign error. Doran and Multer (2009) found that 39 percent all errors were number transposition errors. Some of the discrepancies in findings within the railroad environment may be accounted for by differences in the data collected (e.g., communicators, railroad type, sample size) that was collected by each researcher and differences documented in the error taxonomy created independently by each researcher for coding the radio transactions. Differences in the results between the studies and between the two countries may also be due to differences in regulations and operating practices.

Other than the readback-hearback procedure, another example of a safeguard for controlling miscommunication can be illustrated in the cross-border railway system that runs through Denmark and Sweden. Equipment and procedural differences exist for the two countries; so does terminology, since the two countries do not share a language (Restrup and Sorensen, 2004). Since these difference can be safety risks for effective communications and operation between the two countries, Danish and Swedish language training helps to minimize misunderstandings. Both countries agreed to adopt a restricted vocabulary of 150 terms to use during railroad communications. Communicators were also required to pronounce numbers digit-by-digit to clarify each digit spoken, spell out words the same way as they are spelled (phonetically), and repeat messages back. This gives communicators from both countries identical procedures and protocol—especially important in abnormal conditions.

2.2.3 Message Complexity

As the amount of information exchanged between parties increases, so does the likelihood that the information transfer will be incomplete or result in miscommunication. In the ATC environment, increasing message complexity is associated with increases in incorrect readbacks due to the increasing demands placed on working memory (Morrow, Lee, and Rodvold, 1993; Miller, 1956). Cardosi (1993) showed that there was a 3 percent error rate for clearances (permission from the air traffic controller for the pilot to proceed) containing one to four pieces of information. This rate almost tripled for transmissions containing five or more elements. In an analysis of ground control communications, Burki-Cohen (1995) found that as instructions became more complex the percentage of full readbacks declined and partial readbacks increased as the complexity level rose above three pieces of information. Burki-Cohen (1995) also found that error rates increased as the complexity level rose, unless the information was re-stated. In the railroad environment, Jones and Hickey (2004) found that railroad workers' perception of heightened task complexity led to a greater rate of failed readbacks, ambiguous or incomplete information, and failure to speak clearly throughout the transaction. Minimizing complex processes, through standardized language and the amount of information communicated in a single transmission, contributed to fewer communication errors.

2.2.4 Communicators' Role in Errors

It is also important to look at communication errors by type of communicator. Communication in mainline railroad operations typically involves train crews, dispatchers, and maintenance workers. To understand why the communications took place may help to better understand the situations or role that the communicator plays in making an error. For example, a transaction that occurred between a dispatcher and train crew members would most likely occur as a function of coordinating train movements. If an error occurs more often with a specific group of communicators it may uncover where certain types of errors are most likely.

Jones and Hickey (2004) looked at safety-critical communications between the train crew and signalers[1] to create a baseline measure of their communications and errors. They conducted semi-structured interviews with 24 locomotive engineers and 26 signalers, asking about their perceptions of the biggest safety-critical communication issues. They also listened to 466 transactions between engineers and signalers to see what errors and concerns occurred in real communications in comparison to the perceptions expressed in the structured interviews. Table 2 shows the relative ranking of errors that railroad workers (both engineers and signalers) thought occurred most often compared to the actual ranking of errors.

According to the transcribed communications, the failure to use the correct phraseology (correct units of speech) was the most common transaction error followed by the failure to read back messages and by failure to follow the recognized sequence for communication (e.g., interrupting each other). The biggest difference was the frequency in which the failure to use the correct units of speech was observed. When the engineer shared their perception of safety issues, they ranked failure to use the correct units of speech as the most important safety issue, while the signaler ranked failure to use the correct units of speech as the fourth most important error. Signalers ranked failure to read back the message as the most important error. Signalers stated the failure to use the correct phraseology was an important safety issue, and the data showed it was the drivers who failed to use the correct phraseology. When engineers and signalers were asked about precursors to these errors, engineers ranked lack of experience and distracters most important, while signalers ranked high workload and complexity of tasks as the two most important precursors. These perceptions may have reflected working conditions for each craft. This difference highlights how the role of the communicator differs, how the perspective of the communicator differs, and why these perspectives should be considered when collecting data on communication by both parties.

[1] Signalers are a higher level category than dispatchers in that they include the work completed by dispatcher plus additional roles and responsibilities of which a dispatcher is not in charge.

Table 2. Overall Comparison between Top Three Perceived and Actual Communication Errors

Perceived Errors	Actual Errors
1. Failure to readback message	1. Failure to use correct units of speech
2. Passing on incomplete and/or ambiguous information	2. Failure to read back message
3. Failure to use correct units of speech	3. Failure to follow recognized sequence for communication

Communication errors between signalers and MOW employees in charge (person in charge of possession [PICOP] or controller of site safety [COSS]) have also been examined (Shanahan et al., 2005). The two parties communicate during maintenance work. The signaler oversees train movements and maintaining safety for the railroad via a signal box or control center; when a maintenance issue arises the MOW employee in charge and the signaler verbally communicate so everyone understands where and when it is safe to do the required maintenance. Researchers' transcript analysis identified 41 communication errors out of 188 transactions analyzed with 6 of the 41 errors unrecovered during the transaction. For example, 47 percent of the semantic (meaning *in language*) errors identified were corrected immediately by the speaker who made them. Many of the errors were also identified as omission errors, in which the MOW employee in charge forgot to state their job title (79 percent of the time within sample transactions) and responded to a statement with a readback (83 percent of the time within sample transactions). Numeric information in single numbers (e.g., one-five-three), also documented in the transcripts, can lead to misunderstandings. Numeric information conveyed to maintenance workers was very important to their job. Since these types of transactions contain very little redundant information, readback is crucial. In terms of operating conditions at the time of the miscommunication, two-thirds occurred during normal operating times, one-quarter during degraded conditions and only 8 percent in abnormal conditions and none when an emergency occurred. It was also noted by researchers that most errors occurred in the initial communication between individuals.

Doran and Multer (2009) looked at dispatcher communication at a passenger railroad. Although the goal of their study was to evaluate a wireless handheld computer for railroad roadway workers, they also analyzed a small number of communications between the dispatcher and roadway workers. Findings from their communications analyses revealed that most communications (58 percent) involved information requests, such as requests for movement from one location to another. The authors also found that some causes of voice radio system communication errors occurred because of noisy radio communications that included interference, fadeout, and sound distortion. These potential causes of communication errors via voice communications give credibility to communicating visually, using text and graphics rather than using exclusively aural methods (radio communication). Of the errors found in the transactions, the most common was number transposition, which accounted for 39 percent of the errors. Incorrect information/identification and incorrect time of day accounted for an additional 39 percent of the overall errors. Although incorrect or omitted information was found in the communications between maintenance workers in the studies described above, number transposition was not found to be an issue within their communication sample. However, past findings showed that while digital communication technology might be beneficial with longer, more complex communications, shorter transactions that require a one-word response were quicker and easier for the communicator using an aural system such as a phone or radio (Masquelier, Sheridan, and Multer, 2004).

The purpose of the current study is to provide a baseline against which the use of new communication technologies and means of communication can be compared. How will communication change with these new technologies? What kinds of errors will be eliminated by the new technologies and what new sources of errors could these technologies create? Providing baseline information about current aural, radio-based communications will serve as a basis for comparing these communication technologies as they develop.

3. Methods

This section describes the methods used in this research.

3.1 Operations Data and Sample Size

In the current study, researchers sampled communications in mainline operations from three Class I freight railroads. Radio communications in time blocks consisting of 8 to 24 hours each over 13 non-consecutive days from March 2005 to June 2006 were received from railroads (see Table 3 for breakdown by railroad and territory type). Transactions from 249.5 radio hours were evaluated—a total of 6,060 transactions. Of those, 1,051 were deemed uncodable, and 42 had only one communicator leaving a total of 4,973 transactions involving communication between two individuals. Researchers sampled 6 desks or territories out of a total of 202 desks/territories across the 3 railroads (approximately 3 percent). Note that freight operations differ from passenger operations in two important respects. First, most freight operations are unscheduled. Second, the freight environment has a higher transmission density than the passenger environment, which yields more data per time period than passenger operations.

Table 3. Recoding Day Broken Down by Railroad and Territory Type

Railroad & Territory Type	Days of Recorded Audio Data					
Railroad 1	**5/11/2006**	**5/12/2006**	**5/13/2006**			
Mixed Territory	24 hours	24 hours	24 hours			
Signal Territory	17 hours	17 hours	22 hours			
Dark Territory	24 hours	17.5 hours	24 hours			
Railroad 2	**3/5/2006**	**3/6/2006**	**3/17/2006**	**3/18/2006**	**3/19/2006**	**3/20/2006**
Dark Territory	24 hours	none	24 hours	24 hours	24 hours	24 hours
Mixed Territory	12 hours	8 hours	none	none	none	none
Railroad 3	**6/27/2006**	**6/28/2006**	**6/29/2006**	**6/30/2006**		
Signal Territory	24 hours	24 hours	24 hours	24 hours		

As shown in Table 3, the transactions originated from three types of territories within the three railroads. The types of territories are listed below.

Dark Territory (non-signaled): In dark territories, the train crew relies on direct conversations (voice radio communication) with the dispatcher for information regarding track occupancy and speed restrictions (FRA, 2008). Two methods are used in dark territory operations: 1) track warrants, when information is directly relayed verbally to the train crew by the dispatcher; and 2) train orders, where the train crew is asked to comply with a timetable specified by the dispatcher. Dark territory operations are also subject to general speed limitations assigned by the dispatcher. In this study, the maximum speeds were 49 mph for freight trains and 59 mph for passenger trains; most of the traffic was comprised of freight trains.

Signal Territory: In signal territory, the trains' speed and authority to occupy track was communicated by wayside and/or in-cab signals (FRA, 2008).

Mixed Territory: Mixed territory included a combination of both dark and signal territories, as described above.

3.2 Preparation for Analysis

To properly identify and code the transactions from the digital voice recordings, two computer programs were used. Sony Sound Forge 8.0, an audio editing software, and FileMaker Pro were used to create a database for data storage and to classify each transmission using a taxonomy of message content and error types created by the authors to categorize the type of information found within the transactions, such as the communicators' identify, the purpose of the transaction, and the type of error that occurred in each transaction. See Appendix A for the complete taxonomy of operational factors and their associated definitions. Data from Railroad 2 and Railroad 3 were sent to Volpe with the silent portion of the dispatch recordings removed. Without the time elapsed between transactions available, any analyses that involved the transaction length for Railroad 2 and Railroad 3 could not be determined.

3.3 Data Management

The first step in analyzing the data sample was to extract and identify transactions from each railroad data file. The authors defined a transaction as the discrete exchange of information between two parties. The beginning of a transaction occurs with the first call, which originates with any employee (dispatcher, train crew, roadway worker, and other railroad personnel) and concludes with the final response from the second party involved in the communication. The second party may also be a dispatcher, member of a train crew, a roadway worker, or other railroad personnel. The transaction is complete when both the initiator and responder verbalize the end of their communication by stating, for example, "XYZ Dispatcher out."

The authors identified 6,066 transactions in the data from the three railroads. Within the 6,066 transactions, 1,051 were identified as uncodable and 43 with only one speaker, leaving the dataset with a total of 4,973 transactions.

A transaction was considered uncodable if the coder could not decipher what the speaker said or if the coder determined the information lacked sufficient content to code. For example, a transaction's contents were deemed "insufficient to code" when the transmission was garbled or only contain sounds from equipment such as a telephone. Transactions with only one speaker usually involved the dispatcher attempting to contact another party and the other party did not respond after repeated tries by the initiating (originating) speaker. The transaction would end when the initiating speaker would repeat their identification (ID) followed by speaking the word "out." This behavior indicated that the initiator had stopped trying to contact the other party. In other words, there was not enough information provided by the speakers in the transaction, if any, for the data coder to code the purpose of the transaction. (See Appendix D for a summary of transactions and explanation of uncodable transactions.)

The original sound files from the three participating railroads were labeled by territory and the date that they were recorded. The start of a transaction was identified when the initiating speaker stated their ID followed by "to" and then stated the ID of the intended responding party. For example, "XYZ Dispatcher to ABC123." The end of a transaction was identified when both parties stated their individual IDs following by "out." For example, "XYZ Dispatcher out." After the start and end of a transaction was identified, it was parsed out of the bigger sound file and made to be its own sound file labeled with a unique Transaction ID. The Transaction ID consisted of the territory and facility the original came from, the day on which it occurred, and the order it was entered into the database. Each transaction sound file was entered into the FileMaker Pro database with an assigned Transaction ID as well as the date and length of the transaction. After this information was entered into the database for all transactions, the coder listened to each sound file, one at a time, to code for the major content and error categories as shown in Table 4. A complete list of these categories and their subtypes (12 in total) can be found in Appendix A. As each transaction was coded, all responses were entered into a FileMaker Pro database. After the coding of all transactions was complete all data was converted into a Microsoft Access database for analysis.

Although rare, sometimes one transaction would be interrupted by another transaction. If an intervening transaction occurred within another transaction, then the intervening transaction was taken out of the sound file and placed into a separate sound file containing only this transaction. Most of the time, the intervening transaction was an individual trying to interrupt or speak to the dispatcher. In most instances the dispatcher did not answer them and continued with the original transaction.

Table 4. Content and Error Categories within the Transaction

Transaction Content	Errors within the Transaction
Identification of territory and party	Speech issues
Communicators	Equipment problem
Main purpose	Repeated information
Actions requested by the speaker	Party that committed the error

3.4 Inter-rater agreement

After coding all transactions, the authors measured Cohen's Kappa to test inter-rater reliability between coders. The coder responsible for most coded transactions (56 percent; n = 3,330), was paired with another coder who assisted in coding the transactions in this dataset. Our test showed that Kappa = 0.475 with $p < 0.05$ which is statistically significant. A value of Kappa from 0.40 to 0.59 reflects moderate agreement (Landis and Koch, 1977).

3.5 Calculation of Complexity and Speech Rate

3.5.1 Overview

The authors planned two analyses to examine the impact of transaction complexity and speech rate on errors. The speech rate index refers to the number of syllables spoken by the parties within the transaction divided by the length of the transaction itself. The index measures the amount of information (number of words) transferred between the two parties by syllable. The calculation assumes that each syllable represents a different piece(s) of information. The higher the speech rate index, the more information is communicated. MATLAB® script estimated the speech rate for each recording because manual determination was unreliable. The automated script assumes that the average speech rate for recordings over 10-seconds long can be estimated by counting peaks in the speech signal once high-frequency fluctuations have been removed.

The complexity index was the second method used to measure information passed between parties during a transaction. To calculate this index, coders listened to each transaction and counted the discrete pieces of information passed between the parties (e.g., train ID, track number, direction of train movement etc.). The more discrete pieces of information passed between the two parties in the transaction, the higher the complexity.

The purpose of calculating both the complexity and speech rate index was to help in understanding the factors contributing to communication errors. The authors predicted that communication errors would increase as speech rates and complexity increased, since increasing rates of speech or a message's complexity increases the demands placed on working memory capacity (Miller, 1956).

The speech rate analysis was limited to data from Railroad 1 because the other two participating railroads sent their communications data with the dead space (time between transactions) removed so that an accurate length of the transaction could not be determined.

3.5.2 Complexity Analysis

A complexity analysis was performed to look at the relationship between the complexity index and the number of errors. The complexity index was calculated by counting the number of *discrete* pieces of information transmitted between the two speaking parties within a transaction (repetition of information was not included in this index), such as:

- Greeting and communicator IDs
- Train location
- Direction of the orders
- Time in which a switch was reversed and returned to its normal state
- Track warrant ID numbers
- Head-end train ID
- Malfunctions or emergencies that occurred, milepost locations, etc.

3.5.3 Speech Rate Analysis

A computerized MATLAB algorithm automatically counted the number of syllables in each transaction (See Appendix C for a detailed description of the algorithm). The number of syllables in a sample of errant transactions and transactions not associated with error was divided by the time period of the transactions to determine the speech rate index. Using this methodology, the authors computed whether the speech rate differed significantly between transactions containing errors and transactions not containing errors.

4. Results and Discussion

The original data sample contained 6,066 transactions. A total of 947 transactions were excluded from the analysis because they were deemed uncodable, so a total of 4,973 transactions were included in the analysis. Transactions were initially examined as a whole (see Section 3.2) and later split into independent groups based on the railroad (Section 3.3) and territory (Section 3.4) where the transaction originated.

Thirty-nine percent of all transactions occurred within dark territories, followed by 33 percent within mixed territories and 28 percent in signal territories (see Table 5). Fifty-five percent of the transactions occurred at Railroad 2, 25 percent at Railroad 1, and 20 percent at Railroad 3. Railroad 1's and Railroad 3's smaller percentage of total transactions occurred due in part to a smaller number of transactions available in the original recordings than what was available from Railroad 2.

Table 5. Overall Percentage of Transactions by Railroad and Territory Type

	Railroad			Territory		
	1	2	3	Dark	Signal	Mixed
Transaction Percentage	25%	55%	20%	39%	28%	33%

In the following sections the transaction communicators' purpose, actions, and errors will be identified and discussed in terms of overall transactions and, when warranted, broken further into the railroad and/or territory from which the transactions originated. Findings will be discussed in terms of the individual attributes of the transactions themselves and examined within territories when appropriate.

4.1 Communicators in the Transaction

All completed transactions included an initiator and a responder. The initiator began the communication and the responder responded to the initiator's transmission. Although both parties share roles (i.e., sender and receiver) in a conversation, the authors categorized the speakers based on their initial roles in the transaction. Table 6 shows the breakdown of initiator type by territory. Overall, the dispatcher initiated most (87 percent, n = 4,343) of the communications followed by the train crew with 7 percent (n = 351) and roadway crew and yard crew with approximately 4 percent (n = 108 and 109, respectively) of the communications. The remaining communicators (emergency personnel, taxi service, and unknown) initiated 2 percent of the communications. Initiator by territory shows the same pattern, with dispatchers as the most frequent across territory types. For signal territory, dispatchers initiated communications less frequently than in dark and mixed territories. The absolute number of transactions was smaller in signal territory (1,390 transactions vs. 1,955 for dark and 1,628 for mixed) and can be attributed to the smaller percentage of communications initiated by the dispatcher as the initiator in signal (79 percent), dark (91 percent) and mixed territories (90 percent). Overall, when the dispatcher-initiated communications are normalized by the proportion of total transactions, the relative risk was almost identical across the three territory types. The relative risk for dispatcher-initiated transactions for the three types were: signal: 0.99; dark: 0.99; mixed: 1.00. The primary distinction between dark and signal territory occurred with train crew initiated transactions. The train crew initiated the transaction more often in signal territory (14 percent), than in mixed (4.7 percent) or dark territory (3.9 percent). Overall, roadway crews and yard crews initiated communications about the same amount (4 percent). The overall percentage of communications between roadway crew and yard crews were identical, while the percentage by type or territory differed.

Table 6. Number of Transactions by Initiator Type by Railroad and Territory

		Territory Type		
Initiators	All	Dark	Mixed	Signal
Dispatcher	87.3%	90.8%	90.4%	78.8%
Train Crew	7.1%	3.9%	4.7%	14.2%
Yard Crew	2.2%	3.7%	1.5%	0.8%
Roadway Crew	2.2%	1.0%	2.1%	4.0%
Unknown	0.8%	0.4%	1.0%	1.2%
Other- Taxi	0.4%	0.1%	0.2%	1.0%
Emergency Personnel	0.0%	0.1%	0.0%	0.0%

Most responders across all territory types was the train crew. The train crew was the responder in 72 percent (n = 3596) of transactions, followed by the dispatcher at 14 percent (n = 711) and the roadway crew with 10 percent (n = 451) of transactions. The remaining responders (yard crew, emergency personnel, taxi service, and unknown) accounted for 4 percent of transactions. Responders by territory show the same pattern, with the train crew being the most common responder in signal (63 percent, n = 880), dark (77 percent, n = 1,496), and mixed territories (75 percent, n = 1,220) (see Table 7).

Table 7. Number of Transactions by Responder Type by Railroad and Territory

		Territory Type		
Responders	All	Dark	Mixed	Signal
Train Crew	72.3%	78.0%	73.2%	63.3%
Dispatcher	14.3%	11.9%	15.1%	16.7%
Roadway Crew	9.1%	6.2%	6.6%	16.0%
Yard Crew	2.3%	3.2%	2.5%	0.9%
Unknown	1.7%	0.7%	2.5%	3.2%
Other- Taxi	0.3%	0.0%	0.0%	0.0%
Emergency Personnel	0.0%	0.1%	0.0%	0.0%

Examining pairs (initiators and responders) of communicators showed the same pattern across the three territory types for the two most frequent communication pairs: dispatcher – train crew and dispatcher – roadway crews. Table 8 shows that the percentage of communications by dispatcher – train crew (n = 3832) accounted for most of the communications at 72 percent, followed by dispatcher – roadway crew communications at 10 percent.

For dark and signal territories, dispatcher – yard communications ranked third, followed by dispatcher – dispatcher communications. This pattern was reversed for mixed territories. There was no obvious reason to explain this discrepancy. Overall, the top four communication pairs, all of which involved the dispatcher, accounted for 96 percent of communication transactions. The remaining communications between other parties accounted for the remaining 4 percent. Since communications between the other parties may also have taken place over other radio communication channels not captured on the recordings, the sample underestimates the contributions of communications that involved parties other than the dispatcher.

Table 8. Transaction: Pairs of Communicators by Railroad and Territory

		Territory Type		
Communication Pairs	All	Dark	Mixed	Signal
Dispatcher - Train Crew	77.1%	80.6%	76.4%	72.8%
Dispatcher - Roadway Crew	10.3%	7.0%	7.9%	17.7%
Dispatcher - Yard Crew	4.4%	6.8%	3.9%	1.5%
Dispatcher - Dispatcher	4.0%	3.6%	7.4%	0.7%
Dispatcher - Unknown	1.7%	0.9%	2.3%	1.9%
Train Crew - Train Crew	0.7%	0.5%	0.4%	1.3%
Roadway Crew - Train Crew	0.6%	0.2%	0.3%	1.7%
Unknown - Unknown	0.3%	0.1%	0.4%	0.6%
Not Coded*	0.3%	0.0%	0.0%	0.9%
Train Crew - Unknown	0.2%	0.1%	0.4%	0.3%
Roadway Crew - Roadway Crew	0.1%	0.0%	0.2%	0.2%
Yard Crew - Train Crew	0.1%	0.1%	0.1%	0.1%
Dispatcher - Other	0.1%	0.0%	0.2%	0.1%
Dispatcher - Emergency Personnel	0.1%	0.2%	0.0%	0.0%
Roadway Crew - Unknown	0.1%	0.0%	0.1%	0.1%
Train Crew - Other	0.0%	0.1%	0.0%	0.0%
Yard Crew - Yard Crew	0.0%	0.0%	0.0%	0.1%

Table 9 displays the breakdown of transactions involving a third party in addition to the original communication pair by railroad and territory. Nine percent (n = 471) of the transactions involved a third party communicating with the initiator and receiver. The third-party communicator was defined as an individual who was not part of the initial call and joined once the communication was established. Overall, the most common third-party communicator was another train crew in 86 percent (n = 405) of transactions, followed by the roadway crew in 6 percent (n = 30) of transactions. Third-party communicators by territory showed the same pattern, with train crew being the most common third party in dark (93 percent, n = 162) signal (72 percent, n = 77) and mixed territories (87 percent, n = 166). Looking more closely at the multi-way interactions, the most common interactions, accounting for 76 percent of these conversations, involved interactions between the dispatcher and a train crew that involved another train crew. The second- and third-ranked multi-way conversation involved dispatcher – train crews conversations involving roadway crews and dispatcher – roadway crews involving train crews. Each of these conversations accounted for 4 percent of the total multi-way conversations.

Table 9. Transaction: Pairs of Communicators with a Third Party by Railroad and Territory

			Territory Type		
Initiator/Responder	Third Party	All	Dark	Mixed	Signal
Dispatcher - Train Crew	Train Crew	76.1%	83.3%	81.1%	56.1%
Dispatcher - Train Crew	Roadway Crew	4.4%	3.4%	2.6%	9.3%
Dispatcher - Roadway Crew	Train Crew	4.0%	2.3%	0.5%	13.1%
Dispatcher - Yard Crew	Roadway Crew	2.1%	0.6%	2.6%	2.8%
Dispatcher - Roadway Crew	Train Crew	1.9%	4.0%	1.1%	0.0%
Dispatcher - Train Crew	Yard Crew	1.9%	0.6%	1.1%	5.6%
Dispatcher - Dispatcher	Train Crew	1.5%	0.6%	3.2%	0.0%
Dispatcher - Train Crew	Train Crew	1.5%	1.7%	1.1%	1.9%
Train Crew - Train Crew	Dispatcher	1.3%	0.6%	2.6%	0.0%
Dispatcher - Train Crew	Unknown	1.1%	0.0%	1.1%	2.8%
Dispatcher - Unknown	Unknown	0.6%	0.0%	0.5%	1.9%
Dispatcher - Roadway Crew	Yard Crew	0.4%	1.1%	0.0%	0.0%
Train Crew - Unknown	Train Crew	0.4%	0.6%	0.5%	0.0%
Dispatcher - Roadway Crew	Unknown	0.4%	0.0%	0.5%	0.9%
Dispatcher - Dispatcher	Yard Crew	0.4%	0.0%	1.1%	0.0%
Roadway Crew - Train Crew	Dispatcher	0.4%	0.0%	0.0%	1.9%
Roadway Crew - Train Crew	Dispatcher	0.4%	0.0%	0.0%	0.9%
Dispatcher - Yard Crew	Train Crew	0.2%	0.0%	0.0%	0.9%
Dispatcher - Unknown	Yard Crew	0.2%	0.6%	0.0%	0.0%
Roadway Crew - Roadway Crew	Dispatcher	0.2%	0.0%	0.0%	0.9%
Train Crew - Yard Crew	Yard Crew	0.2%	0.0%	0.5%	0.0%
Train Crew - Train Crew	Unknown	0.2%	0.0%	0.0%	0.9%
Train Crew - Unknown	Train Crew	0.0%	0.6%	0.0%	0.0%

4.2 Message Content

To better understand why a communication took place, transactions were categorized by purpose based on content. There were nine categories or types that could be used to describe the purpose of the communication (transaction). Table 10 shows the nine categories and their definitions. Communications frequently involved a variety of purposes.

In Table 11 below the percentage and frequency for the nine types of message content are presented. The percentages sum to more than 100 percent because each message could address more than one purpose. Overall, the most frequent purpose included in transactions was to Request Action (such as permission to contact another crew, or request that crew stop train/equipment due to a service interruption) at 54 percent, followed closely by the issuing and releasing of authorities at 49 percent (See Table 11 for a complete breakdown of transactions by purpose category). The next three highest purpose categories involved relaying (40 percent, requesting (33 percent), and reporting (25 percent) information. Canceling authorities, cancelling actions, and problems were included in less than 1 percent of the communications.

Table 10. Purpose of Transaction Categories

Message Category	Description
Request Information:	Speaker asks for information.
Request Action (other):	Speaker requests action from receiver. These actions exclude actions associated with authority to occupy track. Examples include permission to contact another crew, request that crew stop train/equipment due to a service interruption.
Issue Authority	Dispatcher issues permission to occupy, perform work, or travel through certain areas of track to train crews, yard crews, maintenance employees and contractors, etc.
Report Information	Speaker provides facts and concerns regarding work and conditions impacting operations. This could include facts about trains, equipment, infrastructure, and environmental conditions, trespassers, etc.
Relay Information:	The speaker shares information with one or more parties that alerts the receivers to situations that may affect their work, such as a dispatcher informing a train crew that there is a delay ahead of them on the tracks because of a stalled train.
Release Authority	The holder of an authority to occupy track surrenders permission to occupy that track.
Cancel Action (other)	An action or request is cancelled, such as cancelling a train's path on a specific track during short-term operations.
Problem Solving	Communicating parties negotiate and brainstorm solutions for problems, such as a train stuck on the tracks. Dispatcher, train crew, and/or local authority coordinate efforts to fix the problem.

Table 11. Percent of Total Transaction by Purpose

Message Purpose	%	Transaction Frequency
Request Action	54%	2,680
Issue Authority	49%	2,456
Release Authority	49%	2,429
Relay Information	40%	1,997
Request Information	33%	1,624
Report Information	25%	1,260
Cancel Authority	<1%	54
Cancel Action	<1%	52
Problem Solving	<1%	44

Table 12 shows the frequency of message complexity as defined by the purposes of the communications. Column 1 shows the potential number of purposes (such as Request Action or Report Information) in a single transaction (message). The number of purposes of a single transaction range from one to five. Column 2 shows the number of transactions. Transaction frequency was inversely related to message complexity. As the number of purposes in a single transaction increased, the number of total transactions decreased. Column 3 shows the unique combinations of message purposes (such as Request Action and Report Information or Relay Information and cancel action) as described in Table 12. Combinations of two and three purposes for a single transaction show the largest number of unique combinations. Appendix B displays the unique combinations of message purpose.

Table 12. Transaction Frequency by Complexity and Unique Types

Message Complexity	Transactions	Unique Types
1	3043	9
2	1522	23
3	305	22
4	55	16
5	3	3

Each transaction's purpose was described using one to nine of the categories listed above. In total, 68 different category combinations were identified in the dataset. The 68 categories are listed in Appendix B. The top ten of the 68 category combinations are listed in Table 13 below. The two most common categories that describe roughly 1,000 transactions each were Release Authority (1,011) and Request Action (999). Interestingly, the most common purpose overall, Release Authority, was only included in one of the remaining nine most common transaction category types (in combination with Request Action, n = 436). The act of Releasing Authority may be most common in communications when no other action is necessary between the communicators or only when requesting an action as well. Specifically, within the Release Authority category, 91 percent requested authority/permission to occupy tracks or sidings, use switches, etc., to complete work assignments.

Table 13. Ten Most Frequent Transactions

Purpose	Frequency
1. Relay Authority	1,011
2. Request Authority	926
3. Request Information and Relay Information	569
4. Request Authority and Relay Authority	518
5. Relay Information	406
6. Request Information	357
7. Report Information	246
8. Request Information and Request Authority	94
9. Report Information and Relay Authority	78
10. Request Information, Request Authority, and Relay Information	78

The average duration of the transactions differed overall based on the purpose of the transactions. Table 14 shows a breakdown by railroad and territory type. For each railroad, transactions that included Cancelling Action took longer than any other type of transaction, with an average of 130.74 seconds (with one exception, Railroad 1). Transactions that included Issue Authority were found to be the second longest overall at 110.7 seconds. Transactions that involved Relaying Information and Requesting Action were found to be the shortest overall (66.94 seconds and 45.89 seconds, respectively). For both dark and mixed territories, transactions that included Problem Solving were found to be the longest, with transactions including Issue Authority second longest but were the longest in signal territories.

Table 14. Duration (seconds) of Transaction by Purpose

	Railroad 1	Railroad 2	Railroad 3	Average Duration
Cancelling Action	134.70	144.00	113.53	130.74
Issue Authority	108.82	99.46	123.84	110.70
Cancel Authority	50.14	87.72	115.35	84.40
Relay Authority	82.25	89.95	61.59	77.93
Problem Solving	37.10	118.14	61.52	72.25
Report Information	44.41	108.01	59.08	70.50
Request Information	51.36	82.29	65.69	66.45
Relay Information	49.57	83.45	67.82	66.94
Request Action	49.42	58.92	29.35	45.89
	Dark	**Signal**	**Mixed**	**Average Duration**
Issue Authority	98.42	106.38	110.85	105.22
Problem Solving	115.65	59.89	119.94	98.49
Cancel Authority	92.85	82.72	73.36	82.98
Relay Authority	81.78	63.15	100.35	81.76
Cancel Action	55.13	37.76	144.00	78.96
Report Information	80.49	59.83	80.78	73.70
Relay Information	77.62	52.41	90.02	73.35
Request Information	78.40	53.18	80.57	70.71
Request Action	53.44	43.51	63.44	53.46

4.3 Action within Transactions

Some transactions occurred due to an action that was planned or executed (e.g., reduced train speed). Actions accounted for 35 percent, or 1,702 of the transactions. There were four different action categories included in this study, including Train Location and Movement, Planning and Cooperative Calls, Safety and Emergency, and Maintenance and Inspection. See Table 15 for a breakdown by frequency of transactions for each type of action.

Table 15. Transactions that Included Actions

Action	Percent	Frequency
Train Location and Movement	23%	1109
Planning and Cooperative Calls	10%	496
Safety and Emergency	2%	80
Maintenance and Inspection	<1%	17
Total	~35%	1702

Findings will be presented for each category of action and how they fell within the different territory types (where appropriate).

4.3.1 Train Location and Movement

Many transactions were initiated to relay information about the location or the movement of the train (n = 505) with 45 percent taking place in a signal territory. For transactions where the train number was reported, the position of the switch and the train movement had the highest frequency at 88 percent ("train position" and "stopped train" were combined in analysis because the position of a train would also encompass where the train was stopped within the territory). Speed restrictions made up the remaining 12 percent.

4.3.2 Planning and Coordination Calls

Other transactions involved planning or coordination activities (n = 496). Of the transactions in this category, 72 percent (n = 360) were coordination calls with 99 percent (n = 357) of the coordination calls involving the coordination of train movements. Of those transactions, 16 percent (n = 78) were categorized as proactively facilitating efficiency, which included a wide range of variables within the transactions so that a more stringent definition of the category was not determinable. For example, if one of the communicators asked for an action in the future, that transaction was coded as proactive. Twenty-nine transactions (6 percent) mentioned an unexpected condition on the tracks, which included an approaching train or an unexpectedly stopped train. Rapport and courtesy calls accounted for the remaining transactions (6 percent, n = 32).

4.3.3 Safety and Emergency Concerns

Several transactions addressed safety or emergency concerns (n = 80). Most calls were in regard to equipment malfunctions (79 percent, n = 63) with 43 percent occurring in the signal territory and 41 percent and 16 percent in the dark and mixed territories, respectively. Ten transactions addressed three separate collisions (seven in the dark territory and three in a signal territory—which will be discussed in more detail in a later section). There were three additional transactions that described obstructions found on the tracks that did not result in a collision. These obstructions all occurred due to a vehicle on the track (two in a dark territory and one in a mixed territory). No transactions were recorded involving trespassing, vandalism, or suicide. The most frequent safety concerns involved signals (n = 25). In some transactions, a false activation occurred in which the signal activated when a train was not in the vicinity or when a signal did not activate when a train *was* in the vicinity. Signal malfunctions were followed, in frequency, by track malfunctions (n = 12), and train malfunctions (n = 9). Some of these cases were due to a track that warped from excessive heat, a broken light, or the train's braking system.

4.3.4 Maintenance and Inspection Issues

Other transactions took place because of maintenance or inspection issues (n = 17) not deemed immediate safety concerns by the communicators. There were 17 transactions classified as non-safety-related maintenance not requiring immediate action and inspection actions. Of the 17, most maintenance issues involved track maintenance (n = 4), with 44 percent occurring in a signal territory. Only one maintenance issue was found that involved the train: this occurred due to issues with the train's engine. Transactions involving inspection issues were in regard to track inspection (75 percent, n = 6) in mixed and dark territories.

4.4 Error Analysis

The authors categorized communication errors two ways. A phraseology error was defined as a failure of the speaker to communicate individual numbers or spell out directions. An example would be if the crew spoke "West on track 2, t-w-o" and failed to spell out "west." An incorrect information error differs in that the spoken information is incorrect. A second type of error can occur during verbal communications when the receiver in a communication pair repeats information incorrectly back to original speaker: this is referred to as a readback error. A readback-hearback error results from a procedure that requires receiver and sender to repeat the information back to the other person to confirm that the information was received and understood correctly. It represents a special class of error because the procedure, itself is designed to minimize communication errors.

4.4.1 Transaction Errors

During any type of communication, errors can occur which put the train crew, MOW, and signal maintainers at risk if they are not discovered and/or corrected. For example, when two speaking parties do not properly identify themselves at the beginning of a transaction and then fail to follow procedure and repeat all information, it may be impossible to catch an error. Therefore, understanding where errors are more likely to occur within a transaction may help explain specific vulnerabilities during railroad communications. In this study, 79 percent (n = 3,930) of the transactions contained at least one error.

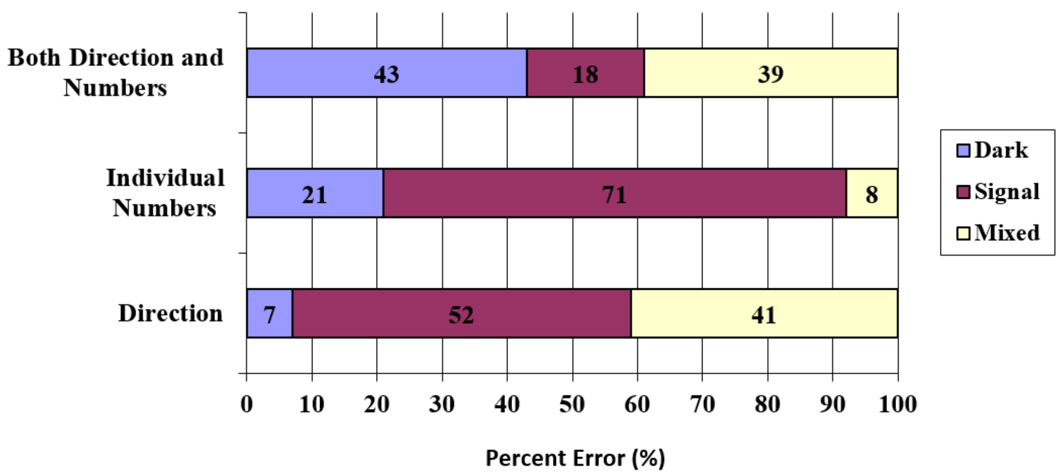
To understand the role message content plays in the likelihood of an error occurring, the authors broke down errors by transaction purpose. Most errors (46 percent) came from transactions with the sole purpose of releasing authority or requesting action. Table 16 gives a breakdown of transaction purpose and the number of errors greater than 1 percent of the total. See Appendix B for the complete breakdown of the overall error count. The Transactions column shows the total number of transactions given the unique purpose as described under the Purpose of Transactions column. The Errors column gives the number of how many individual errors were found in the specific type of transaction, and the column on the far right gives its percent of total errors. For example, Report Information was the sole purpose in 246 transactions. Within those transactions 170 errors were found, which equals to 4 percent of the total errors found in the dataset.

Phraseology errors were the most common error found in the transactions. Phraseology errors were found in 98 percent (n = 3,839) of all transactions, with 11 percent (n = 451) of the errors when speaking individual numbers, 1 percent (n = 27) from speaking the direction only, and 88 percent (n = 3,361) when an error was found with both individual numbers and direction. Within territories, most phraseology errors (errors that included both direction and individual numbers) occurred in dark and mixed territories (40 percent and 35 percent, respectively). For both only direction-based phraseology errors and only individual numbers errors, most occurred in the signal territory – 52 percent for direction errors and 71 percent for individual numbers errors. (See Table 17 for a chart of the phraseology errors by territory). These differences by territory were statistically significant using a Pearson chi-squared test, with all comparisons at $p < 0.001$ between mixed and/or dark territories and the signal territory level for both number and direction phraseology errors.

Table 16. Overall Error Count by Purpose of Transaction

Purpose of Transaction	Transactions	Errors	Percent of Errors
Relay Authority	1,011	888	23%
Request Authority	926	756	19%
Request Information and Relay Information	569	385	10%
Request Authority and Relay Authority	424	378	10%
Relay Information	406	283	7%
Request Information	357	232	6%
Report Information	246	170	4%
Request Information and Request Authority	94	74	2%
Request Authority and Relay Information	94	79	2%
Request Information, Request Authority, and Relay Information	78	61	2%
Report Information and Relay Authority	78	74	2%
Request Action	73	60	2%
Request Information, Report Information, and Relay Information	60	55	1%

Table 17. Distribution of Phraseology Error by Territory



Incorrect information communicated because of a mix-up of the order/sequence of numbers in an ID (regarding a train crew, locomotive, dispatcher, etc.) or authorization/warrant number, referred to as a number with a transposition error, was also examined. In 19 transactions, number transposition errors occurred in a spoken ID and only 3 in terms of location. Of those 22 transactions, 81 percent occurred during communications within a signal territory. The low number of transposition errors was surprising due to the number of transactions analyzed and its common citation in literature regarding communication errors (Doran and Multer, 2009; Jones and Hickey, 2004; Gibson et. al., 2006) for findings of transposition errors).

There were a total of 23 readback errors, with 43 percent in a dark territory, 30 percent in a signal territory and 26 percent in a mixed territory. Hearback errors (type 1 and type 2) were also categorized. Six transactions were found to contain a type 1 hearback error (e.g., when the initial speaker fails to catch the receiver's errors) and seven for hearback type 2 errors (e.g., when the initial speaker fails to catch their own error when the receiver spoke back the erred communication). Partial readback errors (e.g., the repetition of information by the receiver to the original speaker incompletely) were not found in any transactions. See Table 18 for a breakdown of additional error information with readbacks and Table 19 for additional error information on hearbacks.

Table 18. Attributes of Readback Errors

Railroad	Territory	Additional Error Category	Frequency
2	Dark	Phraseology: Number	6
2	Mixed	Phraseology: Number	4
2	Dark	None	3
3	Signal	Phraseology: Number	3
1	Mixed	None	1
2	Mixed	None	1
2	Dark	Phraseology: Direction & Incorrect Information	1
3	Signal	Phraseology: Number & Incorrect Information	1
1	Signal	Phraseology: Number & Number Transposition	1
3	Signal	Phraseology: Number & Number Transposition & Incorrect Info	1
3	Signal	Phraseology: Number & Omission Error	1

Table 19. Attributes of Hearback Errors

Railroad	Territory	Type	Additional Error Category	Frequency
2	Dark	1	None	5
2	Dark	2	None	3
2	Mixed	2	Phraseology: Number	2
2	Dark	2	Phraseology: Number	1
2	Mixed	1	Phraseology: Number	1
2	Mixed	1	Phraseology: Number & Memory Lapse	1
3	Signal	*	Phraseology: Number	1
3	Signal	*	Phraseology: Number & Incorrect Information	1

**Type not coded*

Ninety-five percent of all errors went undetected. Of the 5 percent of errors caught and corrected, 55 percent were catching and correcting another's error. The remaining 45 percent corrected their own error. There is not a large discrepancy between catching one's own versus another's. However, Gibson et al., (2006) found that 85 percent of all errors recorded were caught in the transactions, which is much higher than what this study found.

4.4.2 Other Error Types

Several errors did not fall within the main category types discussed above. Of the "other" errors (defined in Appendix A) the three error types that occurred most frequently were categorized as Incorrect Procedures, Memory Lapses, and Omissions. Incorrect Procedures occur when the dispatcher, train, road or yard crew does not follow standard operation procedure (other than phraseology) and protocol when reporting, relaying, issuing, and/or releasing authority. To code for Incorrect Procedures in the transactions the authors applied the following standard: If the transaction did not follow the typical transaction standard, then it was coded as an Incorrect Procedure. The standard is as follows:

Transactions Begins:

- Responder ID to initiator ID
- Initiator gives information.
- Responder repeats information.
- Initiator corrects any mistakes in responder's repeat.
- Responder repeats the corrections.
- Responder ID Out
- Initiator ID Out

Transaction Ends.

Incorrect Procedures occurred in 75 transactions, or 2 percent of total transactions; 62 transactions, or 83 percent of the transactions, occurred in a signal territory; 7 transactions, or 9 percent, in a mixed territory; and 6 transactions, or 8 percent, in a dark territory.

Memory Lapses are defined as transaction when either the speaker or receiver forgets what was said and needs it repeated or explicitly mentions that s/he forgot to engage in some action. Memory Lapses were found in 45 transactions (less than 1 percent of all transactions); 25 transactions, or 55 percent of the transactions, came from a mixed territory; 14 transactions, or 31 percent, from a dark territory; and 6 transactions, or 13 percent, from a signal territory.

An Omission occurs when either the speaker or receiver leaves out pertinent information in the transaction. For example, if the dispatcher forgets to give the authorization number after reading the authorization to the other party. Omission errors occurred in 132 transmissions (approximately 3 percent of all transactions) with the majority occurring in transactions from signal territories, with 124 transactions, or 94 percent. Both the dark territory and mixed territory categories had 4 transactions (or each with 3 percent of the total omission errors).

For transactions that contained an error(s), some contained multiple error types. A total of 55 different error type combinations occurred within the total number of transactions with errors. The top three most frequent error type combinations all included a phraseology – number error. The most frequent error category was phraseology – number errors, with 3,394 transactions total. Phraseology number and direction was found to be the second most frequent error combination, with 126 transactions and phraseology numbers with omission errors at 115 transactions. See Table 20 below with the top ten error category combinations.

Table 20. Ten Most Frequent Error Category Transactions

Error Type Combination	Transactions
Phraseology - Numbers	3,394 (86%)
Phraseology – Numbers & Phraseology – Direction	126 (3%)
Phraseology – Numbers & Omission	115 (3%)
Incorrect Procedures	40 (1%)
Phraseology – Numbers & Incorrect Procedures	35 (< 1%)
Phraseology – Numbers & Memory Lapse	32 (< 1%)
Phraseology -Numbers & Incorrect Information – Numbers	25 (< 1%)
Phraseology – Numbers	19 (< 1%)
Phraseology – Numbers & General Communication Failure	17 (< 1%)
Phraseology – Number & Readback Error	15 (<1%)

4.5 Communication Equipment Issues

Communication errors could be caused in part by an issue with railroad communication equipment. Poor radio reception was found to be the most frequent equipment error, accounting for 48 percent of all communication equipment problems. Stepped on/blocked transmissions were also found to be a problem in a few of the transactions. This is when the receiver of a transmission only receives a partial communication or no communication because someone had the receiver depressed before or while the other party began speaking or trying to relay a message back before they were done with their transmission. For example, this occurs when different train crews try to contact the dispatcher on the same frequency at the same time. See Table 21 for a summary of equipment problems.

Table 21. Type of Communication Equipment Problems

Problem Type	Number of Transactions
Poor radio reception	131 (48%)
Hot-box blocked communications	73 (27%)
Blocked stepped on communication	44 (16%)
Radio dead spots	17 (6%)
Radio out of service	6 (2%)

Of the transactions that cited poor radio reception, most transactions included at least one error. Errors were classified into five different error categories, including phraseology errors (e.g., the failure to speak individual numbers or spell out directions). See Table 22 for a breakdown of error types due to poor radio reception.

Table 22. Type of Error that Occurred with Poor Radio Reception

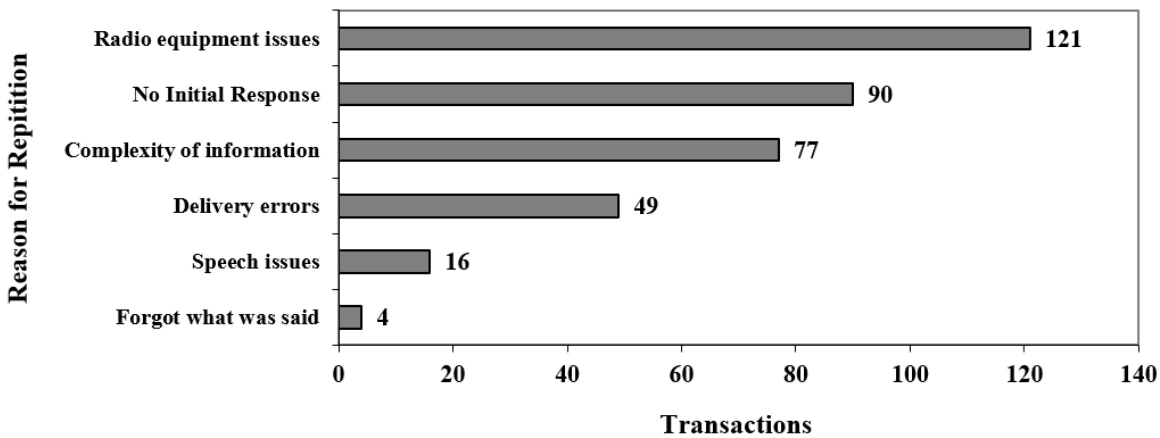
Error Type	Number of Transactions
Phraseology	87 (90%)
General Communication Failure	4 (4%)
Memory Lapse	4 (4%)
Incorrect Information	1 (1%)
Readback/Hearback	1 (1%)

4.6 Speech Delivery Issues and Repeated Information

Miscommunications can occur because of the speakers' poor speech quality. One of the most common speech issues which occurred within a speech error was a hesitation or pause in a response within the transaction (n = 776). This hesitation could have occurred for a number or reasons, such as distractions, although the reasons for the hesitations was not recorded for this analysis. When hesitations occurred, they were most often in a dark territory (55 percent). Surprisingly, only 1 percent of the hesitations were recorded in transactions from a signal territory. There were only three instances where someone spoke too fast. However, this could be an artifact of when and how a coder categorized someone as "speaking too fast." In this study, only if one of the parties explicitly expressed that the other party was speaking too fast was this category counted, which could have overlooked some occurrences.

In some cases, speech quality combined with radio equipment problems contributed to the speaker repeating the transmission. This repetition can cause radio congestion. Additionally, this repetition can be problematic because the speaker may modify the original message, which could change the meaning or omit important detail the receiver needs to understand. Overall, the number of repeated transmissions was small (4 percent, n = 364), with most transmissions repeated due to radio equipment problems such as poor radio reception, radio dead spots, and blocked communications (33 percent). Complex transactions (three or more pieces of information), with a series of numbers and directions also contributed to repeated transmission (21 percent) along with no initial response by the responder (25 percent). Delivery errors, though not as common as radio equipment problems and complex information, were found to be the fourth most common cause of a repeated transmission (14 percent). See Table 23 for a visual representation of reasons of repeated transmissions.

Table 23. Reasons for Repeated Transactions



4.7 Speech Rate and Complexity Analyses

The authors examined the effect of transaction complexity and speech rate on errors. The speech rate index refers to the number of syllables spoken by the parties within the transaction divided by the length of the transaction itself. The purpose for this speech rate index was to provide an objective representation of the amount of information (number of words) transferred between the two parties. The calculation assumes that each syllable represents a different piece(s) of information. The higher the speech rate index, the more information is communicated. The complexity index was the second method used to measure information passed between parties during a transaction. The purpose of calculating both the complexity and speech rate index was to identify and measure the relationship between the length of the transaction/amount of information (speech rate) on an objective level and the amount of information (complexity) on a subjective level, and whether this may have influenced the number and types of errors that occurred during transactions. The speech rate analysis was limited to data from Railroad 1 because the other two participating railroads sent their communication data with the dead space (time between transactions) removed so that an accurate length of the transaction could not be determined. Only Railroad 1 provided researchers with continuous recordings (n = 1,508 transactions).

A Pearson's correlation coefficient was calculated to examine transactions for speech rate indexes with error and complexity index with error. First, transactions were examined for speech rate with error. For the speech rate transactions index, the correlation coefficient was 0.210, $p < 0.1$, which is a non-significant correlation between the two groups (heightened speech rate and errors). In practical terms this revealed that the speech rate index increased marginally (but not statistically significantly) with transactions that included errors. However, the authors did not test if this finding occurred not only when the number of syllables in a transaction increased but depending on the specific type (or purpose) of the transactions. This could also have played a role in the potential for errors to occur.

Regarding the complexity index, which is the count of new information in a transaction, the correlation between the transactions with errors was non-significant at 0.107, $p < 0.1$. A coefficient of that level led to the conclusion that the number of unique items in a transaction was not a good predictor for an error to occur because practically there was no correlation between unique items and number of errors. Comparing between a speech rate index and complexity index (subjective) illustrated that the complexity index and the more objective speech rate index, which counts syllables, had about the same level of predictability for potential errors to occur.

5. Conclusion

The current study expands our understanding of what dispatchers, train crews, and maintenance employees at Class I railroads discuss during mainline operations and the types of errors that occur during these conversations. The information collected can serve as a baseline to compare communications processes and errors as the railroads adopt new technologies that change how employees communicate.

The data suggested that communication errors occurred frequently during normal operations. The authors captured only a subset of communications that took place (since not all communications were recorded by the railroad) and not all errors were documented. Omission errors were particularly difficult to document, as the information was not available in the recording to determine that all the information was communicated. Although the authors captured a large dataset (4,973 transactions representing 384 hours of communications over 16 days), this was a small subset relative to the quantity of communications across the railroad industry. The authors cannot determine how representative this dataset was relative to the population of railroad communications. While the sample represented data from three Class I railroads, overall, the differences between railroad communications were not statistically significant.

One important aspect of the current study was to understand who the communicators were on the freight railroad. The authors found that overall, the most common initiator was a dispatcher in 87 percent of transactions followed by train crew in 7 percent (n = 351) and yard crew in 2 percent of transactions. Overall, the most common responder was the train crew, with 72 percent of transactions, followed by dispatcher in 14 percent of transactions, and roadway crew in 9 percent of transactions. Pairs (initiators and responders) of communicators for each transaction showed that dispatcher/train crew (77 percent) was the most common pair, followed by dispatcher/roadway crew (10 percent) and dispatcher/yard crew (2 percent). The findings differed somewhat from other railroad communication research, where the predominant communicators were signalers or a combination of communicators who did not frequently communicate, as was the case between the dispatcher and train crew (as seen in the current study). This difference may account for other differences seen in the data. For example, Gibson et al. (2006) found that 85 percent of all errors recorded were caught in the transactions—much higher than was found in the current study, with only 5 percent of the errors caught overall, and 45 percent of those caught were done so by the communicators themselves. These differences may have been due to different communication and operating practices between the U.S. and the U.K., or in how errors were defined.

The current study supports findings from Jones and Hickey (2004) and Gibson et al. (2006) that showed many of the errors in radio communication involved standard phraseology procedures, such as direction and individual numbers. However, Shanahan et al. (2005) concluded that none of the lapses in the use of standardized phraseology were found in their sample of incidents. Their findings showed that omission of information or lack of communication at all was the largest cause of miscommunication. Omission errors in the current study were only heard in 131 out of 4,973 transactions, or 3 percent, of the total transactions analyzed. However, the way the authors defined Omission (e.g., where either the initial speaker or receiver leaves out pertinent information in the transaction) may have excluded some omissions that occurred if the interpretation of the definition was more exclusive than intended. Also, it is not always clear when information is being left out or a communication not given; therefore, it was assumed that omission errors were underestimated in this study.

Other studies found that number transposition occurred rather frequently—although this was not the case in the current study, with only 22 transactions, or about 1 percent, of the transactions. Incorrect information in the current study was recorded in 1-2 percent of the transactions, which was the second largest error type found. The incorrect information could have been due to the complexity of the transactions, especially when the transaction was initiated for multiple reasons. Although the studies might differ on what types of communication errors occur most frequently, it was concluded that errors were a frequent occurrence in radio communication.

5.1 Data and Coding Issues

Although the radio communication sample gathered for this study was of considerable size in comparison to past research looking at radio communications in the railroad environment, the sample communications might not have a high level of external validity to everyday experiences in the railroad environment. For example, only three freight railroads were sampled, with limited data from each railroad recorded at the convenience of the railroad, without a sampling plan of times/dates to be followed. Also, many of the transactions recorded could not be coded and used in the study. If this data was coded, it would have given a continuous sample of radio communications instead of missing pieces of communication within the larger dataset. Another factor involved is the actual taxonomy used and the coders who followed its direction. The taxonomy itself was original (created by Volpe staff) and comprehensive but lacked clarification for some variables in terms of what information should be included. More descriptive instructions and examples could have created fewer uncodable transactions and more reliable coding if all coders were using the same taxonomy and understanding it in the same way. Not only was the taxonomy a variable in the findings, so were the coders themselves. Only a moderate inter-rater agreement was found between coders; therefore, there was only a moderate level of confidence in the results.

It could also be difficult for researchers to classify a readback error in radio communication data analysis. Those with experience and expectations for what was to be said would not be listening as intently and may have missed a slip of information, especially if the error was slight in sound (Jones and Hickey, 2004). Therefore, these types of errors were possibly underestimated or not collected in research involving radio communications. However, when looking at factors involved within accidents, Argul (2006) found that the lack of a readback, which could have given the dispatcher an opportunity to catch the error, contributed to at least one fatal accident on Indian railways.

One of the limitations of the current study was that researchers received communications that took place over the radio channels involving the dispatcher. Other radio communications were not captured in the recordings received. These involved direct communications between train crews, roadway crews, and yard crews. To the extent that these communications were missed, this analysis offers an incomplete picture of regular communications. Likewise, our sample of 6 desks out of more than 270 desks means that the sample could have misrepresented the frequency of the content and errors.

5.2 Next Steps

Several possibilities for future work could build upon the current study. First, the current transactions could be re-examined to focus on repeated information from the dispatcher due to location, while additionally looking at the time between transmissions to understand workload conditions (including abnormal situations). Also, if communications were omitted as part of the transaction would be an interesting follow-up to Shanahan et al. (2007) found was the in many of miscommunications. Future studies could also consider the complexity of the transactions themselves as another contributing factor to the situation awareness (or lack thereof) of the communicator.

A potential follow-on task would be to look at FRA incident/accident reports and National Transportation Safety Board accident reports for a specified period of time to see if communication was mentioned either as a precursor to the accident/incident or causal factor in the event itself. This task would include a taxonomy that could capture the effects of communication even when the communication itself might not be a causal factor, but rather a contributory factor to the incident. This task would give researchers the ability to explore the relationship between communication errors and the occurrence of events. Murphy (2001) found that on average only 33 related incidents occur per year involving communication errors in maintenance-related incidents. This number is relatively small, though any number of incidents is too many. Further research using incident/accident reports could be compared with Murphy's (2001) finding to explore incidents (other than maintenance-related ones) to understand if the role and responsibility of some communicators place them more at risk for communication errors that lead to an incident.

Another follow-on task could be to compare communication errors and procedures across transportation modes. A comparative literature review of communication data, including the occurrence of errors, may give a better understanding of what works well within each mode, according to their procedures and training, and what may be applied cross-modally. Research should be included from outside of the U.S. to understand research interests and best practices in railroad communication worldwide and how they may be applied. For example, recommendations for safety across modes could be introduced to understand the higher level issues (such as training) involved in safe radio communication. Future comparisons across modes could look at each mode's considerations for datalink communications as well as what impediment different modes have experienced during their growth from relying solely on radio communication.

5.3 Potential Mitigation Strategies

Aural communication is a complex process that can be taxing on a person's memory, especially when the messages themselves have multiple purposes. This complexity can lead to communication errors that initiate safety issues on the railroad. For example, communication errors such as readback/hearback errors or omissions of information can occur because the parties do not remember precisely what was just spoken to them. It is important to find ways to minimize the distraction for the parties involved in the communications. These can include rules and regulations, responsibilities placed on the communicator, or even the advancement of technology which could also lower the level of distraction during communications. Other issues involving radio communication include frequency congestion as well background noise which can cause the parties to misunderstand each other and, in some instances, fail to catch errors such as when one party is reading back critical instructions (Doran and Multer, 2009). One way to potentially lower the number of errors would be with digital communication. With digital communication the parties would receive requests or instruction in text, decreasing the potential for miscommunication due to the aural-only aspect of communication and its respective equipment. However, datalink communication can also bring up additional considerations, such as lengthy head-down time, which is not an issue in radio communication alone. If radio communication continues to be part of the communication relay in the railroad system, enhanced training for all railroad employees in procedures in communication could be a great benefit. Training established and standardized throughout the railroad culture has the potential to reduce the errors that occur during radio communication. Although many believe that on-the-job training is the best way to learn the procedures and be able to detect errors when they occur, a standardized training curriculum, which includes recurrent issues, could give everyone a foundation to build upon and move forward so that employees are not trying to catch up with technology advances in communication.

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Appendix A.
Taxonomy of Operational Factors

This appendix contains the list of the factors coded while listening to railroad transactions. Each factor is listed with a corresponding definition for a more comprehensive understanding of what information was extracted from the transactions.

GENERAL INFORMATION	
Coder's Name	Coder at the Volpe Center who coded the transaction
Facility ID	To protect the identity of the railroads the actual names have been replaced with RR1, RR2, & RRIII. RR1 = railroad #1; RRII = railroad #2; RRIII = railroad #3.
Territory	Some railroad facilities supplied us with different territories within their jurisdiction. For each of the three railroads each territory was represented with a lower case letter (e.g., a,b,c,). The following territories were recorded as part of the study: Dark Signal Mixed (combination of dark and signal)
Date of transaction	Date that the actual recording took place.
Transaction ID	This identifier is a unique alphanumeric code where numerals are indicative of time and coding sequence. An example of a transaction ID is RRI_RRIb_0001. RRI_RRIb_0002 would have occurred after RRI_RRIb_0001. Within the above example, "RRI_RRIb_0001" • "RRI" – identifies the Railroad facility the transaction originated • "RRIb" – identifies the territory within the railroad facility that the transaction originated • " 0001" – identified the order in which the transaction was entered and coded in the database
Call interrupted by "time-stamped" voice	In some instances, an automated voice will interrupt a transaction with the time and date of that exact moment when the transaction is occurring. This was coded using a yes/no distinction.
Total duration of transaction	The length of time of the transaction. This was recorded in seconds from the beginning of the transaction to the conclusion. *NOTE: Transaction duration (RRI only; RRII and RRIII have duration counts but are not accurate because dead spots were taken out of the sound files)*
Number of transmissions per call	How many times each communicator spoke during the transaction.

COMMUNICATORS The following fields were used for identifying both initiators, responders and (if applicable) third-party communicators	
Dispatcher ID **Roadway Crew ID** **Yard Crew ID** **Train Crew ID** **Emergency Personnel**	
CONTENT OF TRANSACTION (COMMUNICATION GOALS)	
Purpose of transaction	**Request Information –** Information is asked for during transaction
	Request Action – Speaker (dispatcher, train, road, yard crew, etc.) asks for action to be done, such as to issue permission, to contact another crew, to stop due to an unexpected interruption in service. **Issue Authority** – Dispatcher issuing permission to occupy, use or travel through certain areas of track to train, road, yard (etc.) **Other Action** – (Specified by coder)
	Report Information – Train, road, yard, etc., crew provides facts regarding their train, travel, personnel, etc.
	Relay Information – The passing of pertinent information between two parties that alerts to situations that may affect their work indirectly such as a dispatcher informing a train crew that there is a delay ahead of them on the tracks because of a stalled train.
	Release Authority – Train, road, yard, etc., surrenders permission to occupy, use, or travel through certain areas of track.
	Cancel Action – Order or request is nullified. In most cases it is done to cancel an authority. **Cancel Authority/Action** – Dispatcher nullifies orders **Other Action** – (Specified by coder)
	Problem Solving - Communicating parties negotiate and brainstorm solutions for particular situations, such as a train stuck on the tracks. Dispatcher, train crew, and/or local authority coordinate efforts to fix the problem.
Subcategory of Purpose category: Maintenance/Inspection	**Maintenance** – Call involving coordination of maintenance for the track, signal, train and/or switches. **Inspection –** Call involved coordinating an inspection of track, signal, train, and/or switches.
Subcategory of Purpose category: **Train Location/Movement**	**Speed Restrictions –** Slow orders that dispatchers or track foremen impose on certain areas of track in which work is ongoing. These orders are given to train crews going through certain areas of track.

[This is in accordance with rule GCOR-9.14 and NORAC-251 in which trains, that are on tracks designated in a timetable, will move with the current of traffic if the dispatcher gives authorization.]	
	Train Position – Location of train on the track within the subdivision, milepost information needed.
	Stopped Train - Train stalled/paused on the tracks.
	Approaching Train - Train nearing an area of track in question.
	Report Switch Position - Train crew reporting to the dispatcher times in which the track switches were reversed and returned back to normal.
	Perform Manual Switch Operation - Train crew informing dispatcher of a necessity to perform a manual switch operation.
	Movement Against Traffic Current - Train was moving in the opposite direction on the tracks than is generally customary in normal operations.
	Equipment Failure/Malfunction - Train brakes, train lights, switch, signal, or track do not work properly. **Below is the list of factors used in coding a failure/malfunction:** **Train** Breaks Lights **Switch** **Signal** **Track** **Mechanical Issues** Broken Rail Over-heated Rail (hot-box) Other Mechanical Issue **Physical Obstruction** - An object on the tracks hindering travel. **Inclement Weather** - Weather mentioned as an impedance to train movement.
Subcategory of Purpose category: **Safety/Emergency**	**Sign Issues** (Refers to wayside signage along the tracks informing of milepost number) Missing Broken Obscured
	Personal Injury - A person who has suffered an injury from an accident (physical or psychological)

	Malicious Act Trespassing Vandalism Suicide
	Derailment - Train come off the tracks and can no longer operate.
/	**Collision**- The impact of the train with an object on the tracks. The types of collisions include: Train/Train Train/Object-Animal on Tracks Train/Person Train/Road Vehicle
	Poor Visibility - Level and degree of sight impaired. An example would be heavy fog or snow storm on the tracks impairing the view of the crew.
Subcategory of Purpose category: Planning/Cooperative Calls	**Courtesy calls** - Not mandated by operating rules, but improves efficiency of train/track operations. For example, informing roadway workers that an unexpected train will be approaching their location.
	Alert to unexpected conditions – Communicating party passes information about a situation to another party that they would not have otherwise known about. For example a dispatcher alerts a road crew on the tracks of a train heading toward them…
	Proactively facilitating efficiency – Communicating party warning about potential delays or hindrances on the tracks. For example a train crew relaying information regarding a group of cows crossing the tracks.
	Coordination Calls - Communicating parties specifically coordinating crews, cars, trains, etc., the movement of trains. For example, a train crew coordinating the arrival of their taxi to take them back to base after their tour of duty is finished.
	Coordinating movement of trains - Communicating parties specifically coordinating the movement of trains For example a yard crew moving cars and trains in the yard to accommodate an arriving train.
	Coordinating train movement with MOW operations - Maintenance of Way (MOW) - Operations for the maintenance of railroad rights of way. The MOW can include procedures from the initial grading of the right of way to its general upkeep and eventual dismantling. For example, dispatcher delaying trains through a section of track to allow MOW machinery to complete their work.
	Personal conversations - Personal conversations not related to operations. For example, a dispatcher and a train crew speaking about what activities they have planned for their time off work.
SKILL BASED ERRORS Skill based errors are human errors in which standard operating procedures are not followed. An example is when two speaking parties do not properly identify themselves in the beginning of a transaction and then fail to follow procedure and repeat all information they are given to ensure correct transmission.	

Phraseology	A failure of dispatcher/train crew to speak individual numbers or spell out directions. An example would be if the crew spoke "West on track 2, t-w-o, and failed to spell out "west" Specifically, factors were coded as: **Failure to spell out direction** **Failure to state individual numbers** **Other (Specified by coder)**
Number transpositions	Mixed up orders/sequence of numbers in an ID or authorization/warrant number. **ID** – Identification number of the train crew, locomotive, dispatcher, etc. **Location** - milepost number, grade crossings are sometimes given an ID number, etc. **Other** (Specified by coder)
Incorrect Information	The dispatcher, train, road or yard crew, etc., has relayed or reported the wrong information to another party. The information was coded using the following categories: **Location** **Milepost** **Track Number** **Direction** **Date or Time of Day** **Other (Specified by coder)**
Readback/Hearback Errors	**Readback Error** – Receiver repeats information incorrectly back to original speaker. **Hearback Error** - Speaker does not catch/hear the incorrect readback of information repeated from the receiver. There are 2 types of hearback errors: **Type 1** (Fails to catch receiver's error) **Type 2** (Fails to catch own error) **Partial Readback –** the repetition of information from one of the speaking parties is incomplete with some correct and some incorrect information.
Memory Lapse	Either speaker or receiver forgets what was said and needs it repeated or mentions (s)he forgot to engage in some action.
Incorrect Procedure	Dispatcher, train, road or yard crew, etc., does not follow standard operation procedure and protocol when reporting, relaying, issuing, and/or releasing authority.
Omission Error	Either speaker or receiver leaves out pertinent information in transaction. For example if the dispatcher forgets to give the authorization number after reading the authorization to the other party.

General Communication Error	Error that cannot be categorized using above distinctions. The specified error is documented by the coder.
OTHER INFORMATION	
General description of the transaction	Provides detail, context and description about what information was transmitted between the speaking parties and what the transaction accomplished.
General Comments	Any notes that coder wanted to include regarding the coding process on the individual transaction.
Transaction Uncodable	**Coder unable to code** – Coder was unable to hear/determine what was being said during transaction, an example would be if there was too much static coming through over the radio. **Hot Box detector**
Did any information have to be repeated?	Message had to be repeated in the transaction due to: **Complexity of information** **Delivery Errors** **Radio Equipment Issues (e.g. static)** **Speech Issues** **Other (Specified by coder)**

Appendix B.
Purpose of Transactions

Below is the overall breakdown of transactions analyzed regarding their purpose. For many transactions, the purpose was a combination of several categories.

Table B1. Purpose of Transactions

Purpose of Transaction	Total Number of Transactions
Relay Authority	1,011
Request Authority	926
Request Information and Relay Information	569
Request Authority and Relay Authority	424
Relay Information	406
Request Information	357
Report Information	246
Request Authority and Relay Information	94
Request Information and Request Authority	94
Report Information and Relay Authority	78
Request Information, Request Authority, and Relay Information	78
Request Action	73
Request Information, Report Information, and Relay Information	60
Relay Information and Relay Authority	50
Report Information and Relay Information	48
Request Information and Relay Authority	42
Request Information, Relay Information, and Relay Authority	35
Request Information, Request Authority, and Relay Authority	32
Request Information and Request Action	31
Request Authority and Report Information	27
Request Information, Request Action, and Relay Information	22
Request Information and Report Information	18
Request Authority, Relay Information, and Relay Authority	17
Request Authority, Report Information, and Relay Authority	17
Cancel Authority	14
Request Information, Relay Information, and Problem Solving	14
Request Information, Request Authority, Relay Information, and Relay Authority	14
Request Action and Relay Authority	12
Request Action and Relay Information	12
Request Information, Report Information, Relay Information, and Problem Solving	9
Request Information, Request Authority, Report Information, and Relay Information	9
Other	7
Request Authority, Report Information and Relay Information	7
Request Authority and Cancel Authority	6
Request Information, Problem Solving	5
Report Information, Relay Information, and Relay Authority	4
Request Action, Relay Information, and Relay Authority	4
Request Information, Report Information, Relay Information, and Relay Authority	4
Request Information, Request Authority, Report Information, Relay Information, and Relay Authority	4
Problem Solving	3
Relay Information and Problem Solving	3
Request Information, Request Authority, and Report Information	3

Purpose of Transaction	Total Number of Transactions
Cancel Authority and Problem Solving	2
Relay Information and Cancel Authority	2
Request Action, Report Information, Relay Information, and Relay Authority	2
Request Authority, Report Information, Relay Information, and Relay Authority	2
Request Information, Relay Information, Cancel Authority, and Problem Solving	2
Request Information, Report Information, and Relay Authority	2
Request Information, Request Action, and Relay Authority	2
Request Information, Request Authority, Report Information, and Relay Authority	2
Relay Authority and Cancel Authority	1
Relay Authority and Problem Solving	1
Report Information, Relay Authority, and Problem Solving	1
Report Information, Relay Information, and Cancel Authority	1
Request Action and Report Information	1
Request Action, Relay Information, and Problem Solving	1
Request Action, Report information, and Relay Information	1
Request Authority and Problem Solving	1
Request Authority, Relay Authority, and Cancel Authority	1
Request Authority, Report Information, Relay Authority, and Problem Solving	1
Request Information and Cancel Authority	1
Request Information, Relay Information, and Cancel Authority	1
Request Information, Relay Information, Relay Authority, and Problem Solving	1
Request Information, Report Information, Relay Authority, and Problem Solving	1
Request Information, Request Action, and Report Information	1
Request Information, Request Action, Relay Authority, and Other	1
Request Information, Request Action, Relay Information and Relay Authority	1
Request Information, Request Action, Report Information, and Relay Information	1
Request Information, Request Action, Report Information, Relay Information, and Cancel Action	1
Request Information, Request Action, Report Information, Relay Information, and Other	1
Request Information, Request Authority, and Problem Solving	1
Request Information, Request Authority, Relay Information, Relay Authority, and Problem Solving	1
Request Information, Request Authority, Report Information, and Cancel Action	1
Total	4,928*

*45 had no purpose coded

Table B2. Combination of Errors per Transaction by Territory and Railroad Total

Combination of Errors	Dark	Signal	Mixed	Railroad Total
Phraseology – Numbers	1,404	758	1,232	3,394
Phraseology – Direction Phraseology – Numbers	91	0	35	126
Omission Phraseology – Numbers	2	110	3	115
Incorrect Procedure	4	34	2	40
Incorrect Procedure Phraseology – Numbers	2	28	5	35
Memory Lapse Phraseology – Numbers	9	4	19	32

Combination of Errors	Dark	Signal	Mixed	Railroad Total
Incorrect Information – Authority Number Phraseology – Numbers	9	4	12	25
Phraseology – Direction	1	9	9	19
General Communication Failure Phraseology – Numbers	0	1	16	17
Phraseology – Numbers Readback Error	6	3	4	13
Number Transposition - ID Phraseology – Numbers	0	10	2	12
Omission	2	8	0	10
General Communication Failure	2	1	5	8
Incorrect Information – Date or Time of Day Phraseology – Numbers	1	1	5	7
Memory Lapse	5	0	1	6
Hearback Error Type 1	5	0	0	5
Incorrect Information – Other	3	0	2	5
Incorrect Information – Direction Phraseology – Numbers	0	4	0	4
Incorrect Information – Location Phraseology – Numbers	1	2	1	4
Incorrect Information – Milepost Phraseology – Numbers	2	0	2	4
Readback Error	3	0	1	4
Hearback Error Type 2	3	0	0	3
Number Transposition - ID	0	3	0	3
Omission Phraseology – Direction	0	3	0	3
Incorrect Information – Date or Time of Day	0	0	2	2
Incorrect Information – Direction	0	2	0	2
Incorrect Information – Other Omission Phraseology – Numbers	0	1	1	2
Memory Lapse Omission Phraseology – Numbers	0	1	1	2
Number Transposition – Location	0	2	0	2
Phraseology – Direction Memory Lapse	0	0	2	2
Phraseology – Numbers Hearback Type II	0	0	2	2
General Communication Failure Number Transposition – ID Phraseology – Numbers	0	0	1	1
General Communication Failure Hearback Type 2 Phraseology – Numbers	1	0	0	1
Hearback Error Phraseology – Numbers	0	1	0	1

Combination of Errors	Dark	Signal	Mixed	Railroad Total
Hearback Error Incorrect Information - Track Number Phraseology – Numbers	0	1	0	1
Hearback Type 1 Memory Lapse Phraseology – Numbers	0	0	1	1
Hearback Type I Phraseology – Numbers	0	0	1	1
Incorrect Information – Date or Time of Day Readback Error	0	0	1	1
Incorrect Information – Direction Phraseology – Direction Incorrect Procedure	0	1	0	1
Incorrect Information – Direction Phraseology – Direction Phraseology – Numbers	0	0	1	1
Incorrect Information – Milepost Phraseology – Direction Readback Error	1	0	0	1
Incorrect Information – Milepost Phraseology – Direction Phraseology – Numbers	1	0	0	1
Incorrect Information – Other – Action: “Dispatcher looking for train and thought the train he was talking to was not the one he was looking for.” Number Transposition – ID Phraseology - Numbers	0	0	1	1
Incorrect Information – Track Number Phraseology – Numbers Readback Error	0	1	0	1
Incorrect Information - Track Number Number Transposition - ID	0	1	0	1
Incorrect Information – Track Number Memory Lapse Phraseology – Numbers	0	0	1	1
Incorrect Information – Track Number Phraseology – Numbers	0	1	0	1
Incorrect Information – Train ID Phraseology – Direction Phraseology – Numbers	0	0	1	1
Incorrect Procedure Phraseology – Direction	0	1	0	1
Incorrect Procedure Phraseology – Numbers Omission	0	1	0	1
Incorrect Procedure – Track Number Number Transposition - Authority Number Phraseology – Numbers Readback Error	0	1	0	1
Number Transposition – ID Phraseology – Numbers Readback Error	0	1	0	1

Combination of Errors	Dark	Signal	Mixed	Railroad Total
Number Transposition – Line number in track warrant Memory Lapse Phraseology – Numbers	0	1	0	1
Omission Phraseology – Numbers Readback Error	0	1	0	1
TOTAL	**1,558**	**1,001**	**1,372**	**3,931**

Appendix C.
Uncodable Transactions

Out of the 6,066 transactions coded from the three facilities, 1,093 transactions were deemed uncodable. A breakdown of uncodable transaction by reason and counts by territory are given below.

Table C1. Uncodable Transaction Breakdown by Reason and Counts by Territory

Uncodable Categories	**Definition of Category**		
Inaudible to Coder	Too much static in recording		
Only One Speaker/Silence	Only one speaker during transaction		
Hot Box detector – Only	Automated communication sent to the train crew listing the train number, speed, and track number.		
Territory	**Mixed**	**Signal**	**Dark**
Inaudible to Coder	40	239	139
Only One Speaker/Silence	267	266	57
Hot Box Detector	36	34	15
TOTAL	343	539	211

Appendix D. Communication Transaction Tables

Table D1. Number of Transactions by Initiator Type , Territory and Railroad Total

	Territory Type			Railroad Total
	Dark	Signal	Mixed	
Dispatcher	1,776	1,096	1,471	4,343
Train Crew	76	198	77	351
Yard Crew	73	11	25	109
Roadway Crew	19	55	34	108
Unknown	8	17	17	42
Other- Taxi	1	14	3	18
Emergency Personnel	2	0	0	2
Total	**1,955**	**1,390**	**1,628**	**4,973**

Table D2. Number of Transactions by Responder Type , Territory and Railroad Total

	Territory Type			Railroad Total
	Dark	Signal	Mixed	
Train Crew	1,525	880	1,191	3,596
Dispatcher	233	232	246	711
Roadway Crew	121	222	108	451
Yard Crew	62	13	41	116
Unknown	13	44	41	85
Other- Taxi	0	0	0	13
Emergency Personnel	1	0	0	1
Total	**1,955**	**1,390**	**1,628**	**4,973**

Table D3. Transaction: Pairs of Communicators by Territory and Railroad Total

Communication Pairs	Territory			Railroad Total
	Dark	Signal	Mixed	
Dispatcher – Train Crew	1,576	1,013	1,243	3,832
Dispatcher – Roadway Crew	137	246	129	512
Dispatcher – Yard Crew	133	21	64	218
Dispatcher – Dispatcher	71	10	120	201
Dispatcher – Unknown	18	27	38	83
Train Crew – Train Crew	9	18	6	33
Roadway Crew – Train Crew	3	24	5	32
Unknown – Unknown	1	8	6	15
Not Coded*	0	13	0	13
Train Crew – Unknown	1	4	6	11
Roadway Crew – Roadway Crew	0	3	3	6
Yard Crew – Train Crew	2	1	2	5
Dispatcher – Other	0	1	3	4
Dispatcher – Emergency Personnel	3	0	0	3
Roadway Crew – Unknown	0	1	2	3
Train Crew – Other	1	0	0	1
Yard Crew – Yard Crew	0	1	0	1
Total	**1,955**	**1,391**	**1,627**	**4,973**

Table D4. Transaction: Pairs of Communicators with a Third Party by Territory and Railroad Total

Communicators	Third Party	Territory Type			Railroad Total
		Dark	Signal	Mixed	
Dispatcher – Train Crew	Train Crew	145	60	154	359
Dispatcher – Train Crew	Roadway Crew	6	10	5	21
Dispatcher – Roadway Crew	Train Crew	4	14	1	19
Dispatcher – Roadway Crew	Roadway Crew	1	3	5	9
Dispatcher – Train Crew	Yard Crew	7	0	2	9
Dispatcher – Dispatcher	Train Crew	1	0	6	7
Train Crew – Train Crew	Train Crew	3	2	2	7
Dispatcher – Train Crew	Dispatcher	1	0	5	6
Dispatcher – Yard Crew	Train Crew	5	0	1	6
Dispatcher – Train Crew	Unknown	0	1	2	3
Yard Crew – Dispatcher	Train Crew	2	0	1	3
Dispatcher – Dispatcher	Yard Crew	0	0	2	2
Dispatcher – Roadway Crew	Unknown	0	3	0	3
Dispatcher – Roadway Crew	Yard Crew	2	0	0	2
Dispatcher – Train Crew	Other	0	2	0	2
Roadway Crew – Train Crew	Dispatcher	0	2	0	2
Train Crew – Dispatcher	Unknown	0	3	0	3
Train Crew – Unknown	Train Crew	1	0	1	2
Dispatcher – Unknown	Train Crew	1	0	0	1
Dispatcher – Unknown	Unknown	0	0	1	1
Dispatcher – Yard Crew	Yard Crew	1	0	0	1
Other – Dispatcher	Other	0	0	1	1
Other – Dispatcher	Train Crew	0	0	1	1
Roadway Crew – Dispatcher	Other	0	1	0	1
Roadway Crew – Roadway Crew	Dispatcher	0	1	0	1
Roadway Crew – Train Crew	Train Crew	0	1	0	1
Train Crew – Train Crew	Dispatcher	0	1	0	1
Train Crew – Unknown	Unknown	0	1	0	1
Train Crew – Yard Crew	Yard Crew	0	0	1	1
Unknown – Unknown	Dispatcher	0	1	0	1
Unknown – Unknown	Other	0	1	0	1
Unknown – Unknown	Unknown	0	1	0	1
Total		**180**	**107**	**191**	**478**

Table D5. Number of Transactions with One Speaker by Type

Type	Number
Train Crew	22
Dispatcher	10
Unknown	10
Total	**42**

Abbreviations and Acronyms

ACRONYM	**DEFINITION**
ATC	Air Traffic Control
FRA	Federal Railroad Administration
ID	Identification
MOW	Maintenance-Of-Way
ROW	Right-Of-Way
Volpe	Volpe National Transportation Systems Center